

76. Others are remotely mounted and receive an electronic or pneumatic signal from the instrumentation element. A typical strip chart type recorder is illustrated in figure 2-96. This particular model can record up to three separate process variables on a 4-inch-wide strip chart, while other models may record up to 20 variables. Both strip charts

and circular charts are in typical use in Army Boiler Plants and generally record two to four variables.

## 2-29. WATER TREATMENT CONTROL.

Instrumentation controls for water treatment systems are discussed in chapter 4.

# SECTION V. POLLUTION CONTROL EQUIPMENT

## 2-30. POLLUTION REGULATIONS.

Control of pollutants from the combustion of fossil fuels in central boiler plants may be required. Boiler plant emission regulations are issued by Federal, state, and local environmental agencies, with the most stringent regulation usually being imposed. Two general types of regulations exist: point source regulations and ambient air quality standards.

**a. Point Source Regulations.** Point source regulations place limits upon the quantity of a pollutant which may be emitted from any stack, regardless of its relationship to local air quality. These regulations should be considered to be the minimum regulations, and, if applicable, must always be met. Typical point source emission levels for the commonly regulated pollutants are listed in table 2-1. In most cases, some or all of these regulations will be inapplicable to Army boilers. Federal regulations do not, at the present, apply to boilers of less than 250 million Btu/hr heat input (approximately 180,000-200,000 pounds of steam/fr). Most state and local agencies also have minimum size limitations.

TABLE 2-1.  
TYPICAL POINT SOURCE EMISSION LEVELS  
FOR VARIOUS POLLUTANTS

Pollutant	Fuel	Maximum Allowable Emission	
		LB-Pollutant/ Million Btu	PPM at 3% O <sub>2</sub>
Particulate	All	0.1	N/A
NO <sub>x</sub>	N.G.	0.12	160
		Oil	0.3 230
		Coal	0.7 510
SO <sub>x</sub>	Oil	0.8	440
		Coal	1.2 630

**b. Ambient Air Quality Standards.** Ambient air quality standards may be applicable to any size boiler. These standards require that the emissions from the unit be considered, as they affect the air quality of the surrounding area. Consideration must be given to meteorological effects and other pollution sources in the area in determining allowable emission levels. The emission levels determined under ambient air quality standards may be the same as, more stringent than, or less stringent than the applicable

point source regulations for a given boiler plant. The actual determination of the applicable limits usually warrants a separate study by a consultant.

## 2-31. TYPES OF POLLUTANTS AND CONTROL METHODS.

The pollutants listed in table 2-1 are those that are commonly regulated from Army boilers. Their generation and control are discussed briefly in this section. More detailed information can be found in TM 5-815.

**a. Oxides of Nitrogen.** NO<sub>x</sub> is the generic name for a group of pollutants formed from various combinations of nitrogen and oxygen. The principal form generated by boilers is nitric oxide, NO. NO is formed when the nitrogen in the fuel and air reacts at high temperature with oxygen from the air. It can be controlled in existing boilers by careful adjustments and modification to the burners aimed at lowering the peak flame temperatures in the furnace and by minimizing the amount of free oxygen available in the highest temperature combustion zones. New boilers which have been purchased to meet specific NO<sub>x</sub> emission regulations will generally have these modifications designed into them. In addition, they will also be designed with larger furnaces and more water-cooled surface in the burner zone to improve heat transfer characteristics and to further reduce the peak combustion temperature attained. Some of the modifications and adjustments which can be implemented are listed in table 2-2, as well as advantages and disadvantages of each and the anticipated reduction in NO<sub>x</sub> emissions. Additional information on these NO<sub>x</sub> reduction techniques is available in Army Manual TM 5-815. However, since relatively few Army boilers are required to meet NO<sub>x</sub> regulations, these topics are not discussed further in this manual.

**b. Oxides of Sulfur.** The primary oxide of sulfur (SO<sub>x</sub>) formed by the combustion of fossil fuel is sulfur dioxide or SO<sub>2</sub>. SO<sub>2</sub> is formed when sulfur from the fuel combines with oxygen from the air in the high temperature zones of the furnace. In a conventional boiler, essentially all the sulfur that enters with the fuel converts to SO<sub>2</sub>. No practical form of combustion modification has been developed to reduce SO<sub>2</sub> generation in the furnace. In order to control

Table 2-2. Comparison of NO<sub>x</sub> Reduction Techniques

Technique	Potential NO <sub>x</sub> Reduction (%)	Advantages	Disadvantages
Load Reduction	25-60	Easily implemented; no additional equipment required	Reduction in generating capacity; possible reduction in boiler thermal efficiency.
Low Excess Air Firing (LEA)	15-40	Increased boiler thermal efficiency	A combustion control system which closely monitors and controls fuel/air ratios is required; possible increase in particulate emissions; increased slagging and ash deposition with coal-fired units.
Two-Stage Combustion	40-50	—	Boiler windboxes must be designed for this application. Not recommended for coal-fired units.
Off-Stoichiometric Combustion (Coal)	15-45	—	Furnace corrosion and particulate emissions may increase.
Reduced Combustion Air Preheat	10-50	—	Control of alternate fuel-rich and fuel-lean burners may be a problem during transient load conditions.
Flue Gas Recirculation	20-50	Possible improvement in combustion efficiency and reduction in particulate emissions	Not applicable to coal-fired units; reduction in boiler thermal efficiency; increase in exit gas volume and temperature; reduction in boiler load.  Boiler windbox must be modified to handle the additional gas volume; ductwork, fans, and controls required.

the release of SO<sub>2</sub> emissions to the atmosphere, it is necessary to either burn a fuel having a lower sulfur content, or use some type of flue gas desulfurization equipment (also called scrubbers) to remove the SO<sub>2</sub> after it leaves the boiler. The most common types of scrubbers used on boilers in the size range employed at Army bases are lime or limestone slurry types, magnesium oxide slurry, double alkali, and lime dry scrubbers. Some of the performance characteristics of these are summarized in table 203. The SO<sub>2</sub> removal systems mentioned above are expensive both to purchase and to operate, and in most cases they cost more than the entire boiler plant. For this reason, they are not cost-effective and generally not used unless dictated by regulations. They are very rarely seen on Army plants, compliance with regulations generally being by means of low sulfur fuel instead. Details on the installation and operation of scrubbing equipment is discussed in detail in Army Manual TM 5-815, chapter 10. Atmospheric fluidized bed boilers are also becoming more commonly applied when control of SO<sub>2</sub> emissions is required. These are generally more cost-effective than scrubbers but have not been commonly applied because of their limited operating experience (reference paragraph 2-18g).

**c. Particulate.** Particulate matter, also called fly ash, is the pollutant that is of most concern to Army boiler operators. It is comprised primarily of unburned carbon and the portion of the ash which is carried through the boiler by the flue gas stream. The quantity of particulate matter generated is strongly dependent upon the characteristics of the fuel. In general, the higher the ash content of the fuel, the higher the particulate emissions. Therefore, coal produces a large amount of fly ash, natural gas produces essentially none, and fuel oil produces a moderate but widely varying amount, depending upon its grade and characteristics. Particulate emissions may be controlled to a certain extent by careful attention to the burners and combustion characteristics of the boiler. However, control of this type is essentially limited to oil firing, since the total particulate matter produced from oil is low and usually contains a large percentage of unburned carbon. Proper combustion control can minimize this unburned carbon and thus substantially reduce the total particulate emission. With coal, the incoming fuel may contain 10 to 12 percent ash, as much as 80 to 90 percent of which may be carried out as fly ash. This ash far outweighs the small percentage of unburned carbon which is produced in the furnace due to incomplete combustion. Changes and adjustments to the burners which minimize the unburned carbon are, therefore, largely ineffective in reducing total particulate emissions. (This is not meant to imply that proper burner adjustment and operation should be ignored on coal-fired boilers, since gains in thermal efficiency can still be realized due to

a decrease in unburned carbon and reductions in excess air.) When coal is to be fired in a boiler, it is necessary to provide particulate emission control by means of a collection device in the flue gas stream between the boiler and the stack. Several suitable types of devices exist, as itemized in table 2-4 and discussed in sections 2-32 through 2-35. In addition to these devices, under some circumstances, tall stacks may be considered a particulate control device. Although they do not remove particulate matter, tall stacks can cause the particulates to be more widely dispersed in the atmosphere, and thus can be a means of meeting ambient air quality regulations. This technique is rarely applicable to Army boiler installations, however. For more details on the use of tall stacks as a particulate control device, refer to Army Manual TM 5-815.

**d. Pollutants from Natural Gas.** Of the fuels commonly burned in Army installations, natural gas is the cleanest. The only pollutant generally associated with natural gas is NO<sub>x</sub>. Since natural gas contains no ash or sulfur, there is no generation of particulate matter or SO<sub>2</sub>.

**e. Pollutants from Oil.** When oil is burned in a boiler, a variety of pollutants can be formed including NO<sub>x</sub>, SO<sub>x</sub>, and particulates. The grades of oil most commonly burned in Army facilities are No. 2 and No. 6. No. 2 oil is highly refined, clean-burning oil having little ash or sulfur and emissions can generally be controlled by burner adjustments without resorting to specialized pollution equipment. No. 6 oil is less refined and therefore cheaper. It can contain up to about 0.5 percent ash and 3.5 percent sulfur. These higher amounts of ash and sulfur lead to higher emission levels. Particulate emission levels from No. 6 oil often become high enough to warrant the use of particulate-control devices. While SO<sub>2</sub> emissions can also become high enough to violate regulations, the use of scrubbing equipment with small boilers is not generally cost effective, and regulations are usually met by conversion to an oil having a lower sulfur content.

**f. Pollutants from Coal.** Boilers burning coal will almost always require a device to control particulate emissions. NO<sub>x</sub> and SO<sub>2</sub> emissions will also be high from most coals. Whether or not control of NO<sub>x</sub> and SO<sub>2</sub> is required depends upon the regulation in effect in the particular locality in question. Control of NO<sub>x</sub> emissions is accomplished by proper design, proper adjustment, and proper boiler and burner operation. Control of SO<sub>2</sub> emissions would usually be achieved by the use of low sulfur coal. In very few instances would the use of SO<sub>2</sub> scrubbing equipment be cost-effective on small boilers.

## 2-32. MECHANICAL COLLECTORS.

The term "mechanical collector" refers to a widely used type of particulate-collection device in which dust-laden

Table 2-3. Performance Characteristics of Flue-Gas Desulfurization Systems

System Type	SO <sub>2</sub> Removal Efficiency (%)	Pressure Drop (inches of water)	Recovery and Regeneration	Operational Reliability	Retrofit to Existing Installations	Advantages	Disadvantages
Limestone, Scrubber Injection Type	30-40	Greater than 6"	No recovery of lime	High	Yes	High reliability; no boiler scaling.	Low efficiency; scaling and plugging of nozzles and surfaces in scrubber solids disposal.
Lime, Scrubber Injection Type	90+	Greater than 6"	No recovery of lime	Low	Yes	High efficiency; no boiler scaling; less scaling in scrubber than limestone in some cases.	Low reliability; solids disposal to landfill.
Magnesium Oxide	90+	Greater than 6"	Recovery of MgO and sulfuric acid	Low	Yes	High efficiency; no solids disposal.	Low reliability; corrosion and erosion of scrubber and piping; need pre-cleaning of flue gas.
Double Alkali Systems	90-95		Regeneration of sodium hydroxide and sodium sulfites	Unknown	Yes	Absorption efficiency potentially higher than other systems; scaling problems reduced; produces solid rather than liquid waste.	Solids buildup in reactor system; problems with dewatering systems.
Lime, Dry Scrubbing	70-90	8" - 10" including baghouse	Lime/limestone may be recovered	Unproven but potentially high	Yes	Lower cost; relatively simple operation; produces solid waste; takes advantage of alkali content of coal ash; uses existing technology.	Unproven operational reliability; applicable only to low/medium sulfur coal; must be used in conjunction with baghouse/precipitator.

Table 2-4. Performance Characteristics of Particulate Control Devices

Device	Maximum Removal Efficiency	Typical Pressure Drop	Advantages	Disadvantages
Mechanical Collector	90-95%	3-6	High reliability; well proven; compact.	Low efficiency on small particle sizes.
Electrostatic Precipitator	99%+	0.2-0.8	High efficiency over a wide range of particle sizes; well proven; reliable; low pressure drop.	High capital cost; very sensitive to ash analysis.
Fabric Filter	99%+	3-6	High efficiency; reliable if properly designed; insensitive to coal type.	Potentially high maintenance; high capital cost; not compatible with oil-only firing; maximum operating temperature of 550 °F.
Wet Scrubber	99%	20-25	High efficiency; can handle high temperatures and heavy loadings.	High capital cost; high O&M cost; solid waste disposal problems; complicated control system; water supply and disposal problems; weather-proofing may be required.

gas enters tangentially into a cylindrical or conical chamber or series of chambers and leaves through a central opening. The resulting vortex motion or spiraling gas flow pattern creates a strong centrifugal force which separates the dust particles from the carrier gas stream by virtue of their inertia. The particles migrate to the cyclone walls by means of gas flow and gravity and fall into a hopper. Because of the pattern of the gas flow through the collector, mechanical collectors are often referred to as "cyclones." Cyclones may be classified according to their gas inlet design, dust discharge design, gas handling capacity, collection efficiency, and their arrangements. Two common types of cyclones employed on Army boilers are the conventional, medium-efficiency, single cyclone, and the multicyclone.

**a. Single Cyclone.** Single cyclones are used to collect coarse particles when high collection efficiency and space requirements are not major considerations. Collection efficiencies of 50 to 80 percent of particles greater than 10 microns are common. A typical configuration is shown in figure 2-97. Single cyclones are 4 to 12 feet in diameter and are limited to about 20,000 actual ft<sup>3</sup>/min gas flow. More than one unit can be combined in parallel to accept greater gas flows.

**b. Multicyclones.** When higher collection efficiencies or higher gas flows are required, it is common to employ the multicyclone. This device combines into a single plenum a large number of small diameter cyclones (6 to 12 inches) of a type shown in figure 2-98. Due to the small diameter, higher inertial forces are generated and collection efficiencies are higher. In addition, it is possible to design multicyclones to handle virtually any gas flow simply by adding more cyclone tubes and mounting more than one unit in parallel into the gas stream.

**c. Other Cyclones.** Other types of cyclones which are less commonly used are the high-efficiency single cyclone and the wetted cyclone. The principal characteristics of the four types are summarized in table 2-5.

**d. Collection Efficiency of Cyclones.** The ability of a cyclone to separate and collect particles from a gas stream is dependent primarily upon the design of the cyclone, the size and quantity of the dust particles, and the pressure drop through the cyclone. Typical collection efficiencies for the various types of cyclones, operating in various applications, are given in tables 2-5 and 2-6. Efficiency estimates for a given application can be made by utilizing the cyclone manufacturer's fractional efficiency curves. An example of a typical fractional efficiency curve is shown in figure 2-99. These curves are determined by actual testing of similar prototypes in the manufacturer's laboratory. Total collector efficiency is determined by multiplying the percent weight of particles in each size range by the collection efficiency corresponding to that size range, and determining

the sum of all the collected weights as a percentage of the total weight of dust entering the collector.

**e. Pressure Drop and Energy Requirements.** Through any given cyclone, there will be a loss in static pressure of the gas between the inlet and outlet. This pressure drop is the result of entrance and exit losses, frictional losses, and loss of rotational kinetic energy in the exiting gas stream. The cyclone pressure drop increases approximately as the square of the inlet velocity. Energy requirements in the form of fan horsepower are directly proportional to the volume of gas handled and the static pressure drop. A rule-of-thumb estimate of fan energy requirements is that one quarter of one horsepower is required per 1000 actual ft<sup>3</sup>/min of gas per 1 in-H<sub>2</sub>O pressure drop. Thus, a mechanical collector applied to a 40,000 lb/hr boiler (approximately 16,000 actual ft<sup>3</sup>/min flue gas flow) and designed to operate at 3.0 in-H<sub>2</sub>O pressure drop would require about 12 horsepower in fan power.

**f. Cyclone Performance.** For cyclone installation, it is desirable to have as high a collection efficiency and as low a pressure drop as possible. Actual in-plant performance will vary from day to day due to changes in operating conditions such as gas flow, dust load, and particle size. In general, changes which increase pressure drop or particle size will improve the collection efficiency, which changes that decrease pressure drop or particle size will decrease efficiency.

**g. Application for Particulate Collection.** Mechanical collectors are used as primary particulate collection devices when the particulate dust is coarse, when inlet loading is heavy, or when high collection efficiency is not a critical requirement. Since collection efficiencies are low as compared to other types of control devices, mechanical collectors are not usually suitable as the primary means of control when emission regulations are stringent. In this case, one of the devices discussed later in the chapter must be applied.

**h. Application as Precleaners.** Another common application of cyclones to Army Central Boiler Plants is as a precleaner in solid fuel combustion systems, such as stoker-fired and pulverized coal-burning boilers. In these units, large coarse particles may be generated and a cyclone collector may be installed ahead of an electrostatic precipitator or baghouse to remove these particles. In the case of a stoker/baghouse combination, a mechanical collector is almost mandatory, since hot or burning particles are often carried over them the fuel bed and could ignite the bags. A combination installation is also ideal from a performance standpoint when applied to a precipitator, because the cyclone exhibits increased collection efficiency during high gas flow and dust loading conditions, while the precipitator shows an increase in efficiency during decreased gas flow and dust loading. The two devices

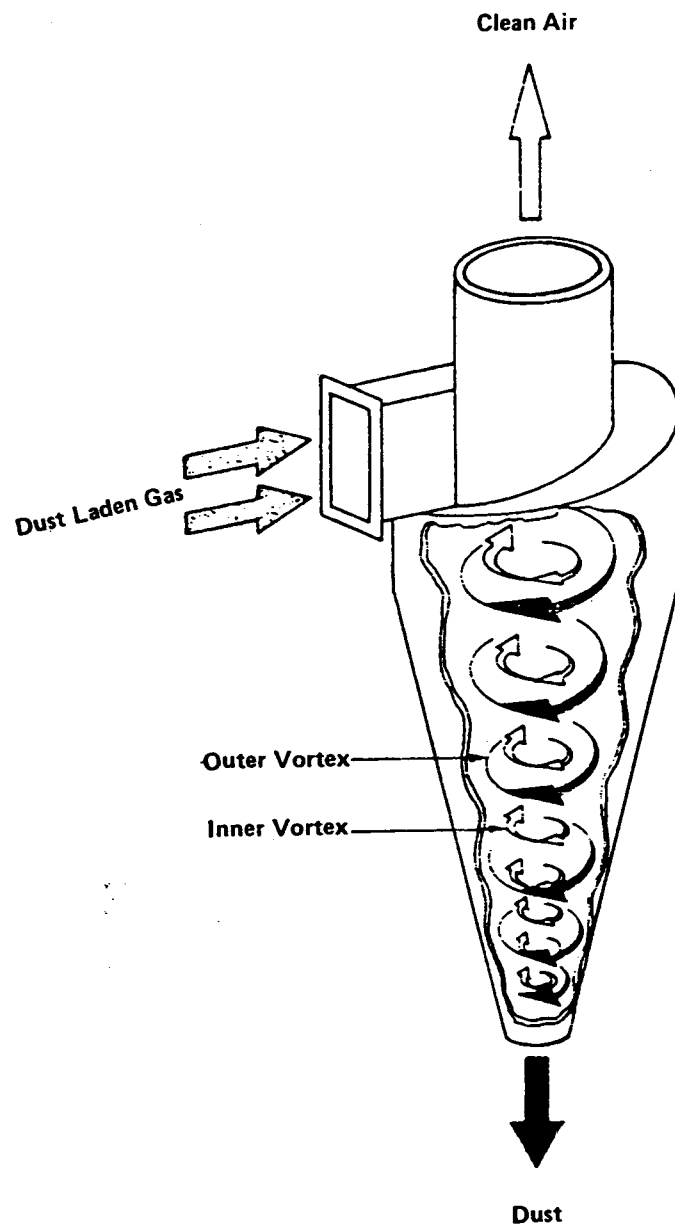
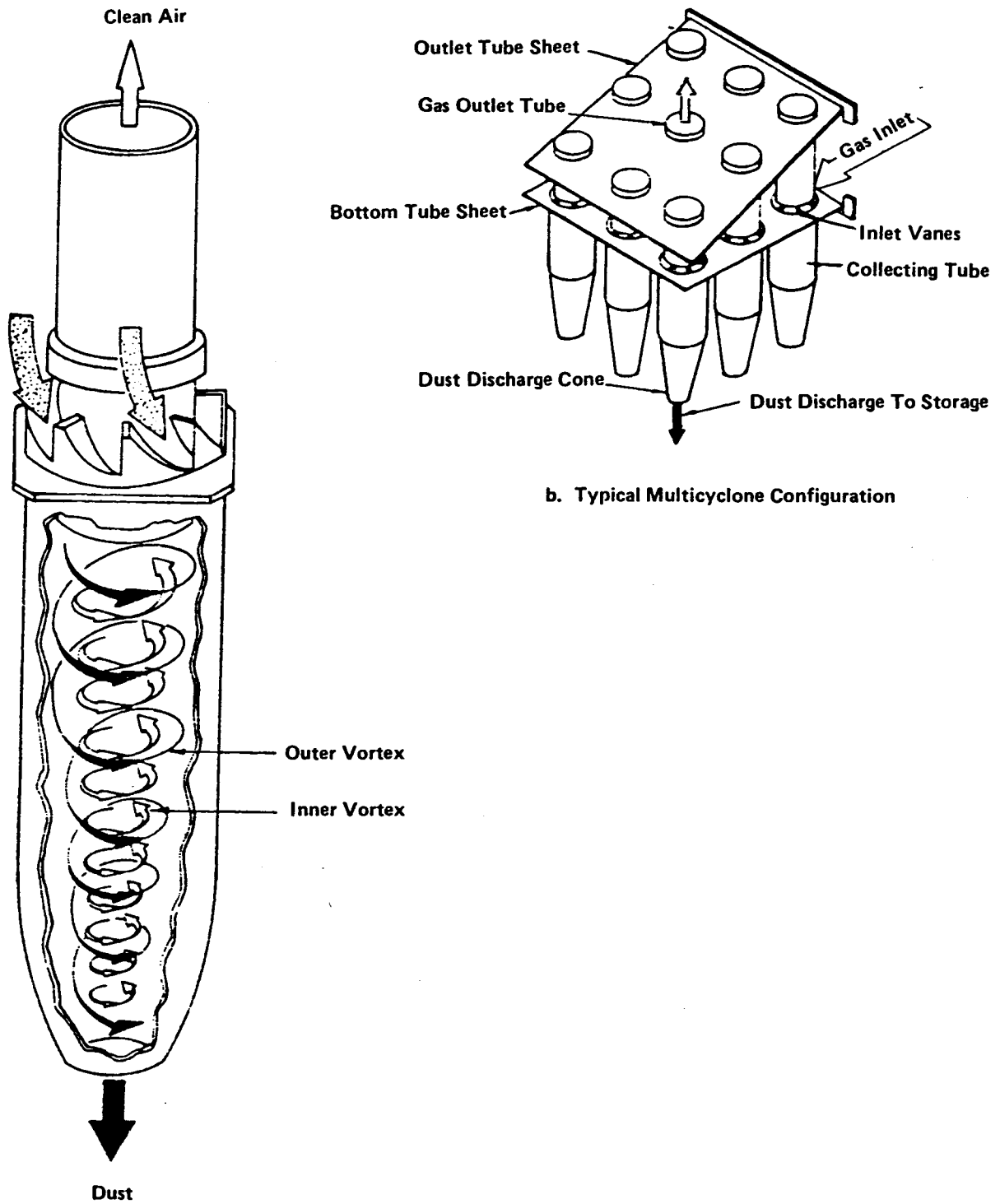


FIGURE 2-97. MEDIUM EFFICIENCY CYCLONE CONFIGURATION



b. Typical Multicyclone Configuration

a. Configuration Of Individual Cyclone Tube From Multicyclone

FIGURE 2-98. MULTI-CYCLONE CONFIGURATION



Table 2-5. Characteristics of Mechanical Dust Collectors

Type	Body Diameter (feet)	Gas Flow (ft <sup>3</sup> /min)	Pressure Drop (in-H <sub>2</sub> O)	Inlet Velocity (ft/s)	Collection Efficiency (%)	Application	Other
Medium-Efficiency Single Cyclone	4-12	1,000-20,000	.5-2	20-70	50-80	Material Handling	Large headroom requirements. Limited to large, coarse particles; large grain loadings.
High-Efficiency Single Cyclone	Less than 3	100-2,000	2-6	50-70	80-95	Exhaust gas pre-cleaner Industrial boiler particulate control	Smaller space requirement; parallel arrangement; inlet vane flow controls needed continuous dust removal system purge operation.
Multicyclones	.5-1	30,000-100,000	3-6	50-70	90-95	Industrial and utility boiler particulate control	Plenums required. Problems: gas recirculation fouling; continuous dust removal system, flow control.
Wetted Cyclone	Less than 3	100-2,000	2-6	50	90-95	Boiler application (low sulfur fuel) (low temperature).	Water rate 5-15 gal/1,000 ft <sup>3</sup> /min; corrosion-resistant materials.

**Note:** Cyclone collection efficiency must be evaluated for each specific application, due to the sensitivity of cyclone performance on gas and dust properties and loadings.

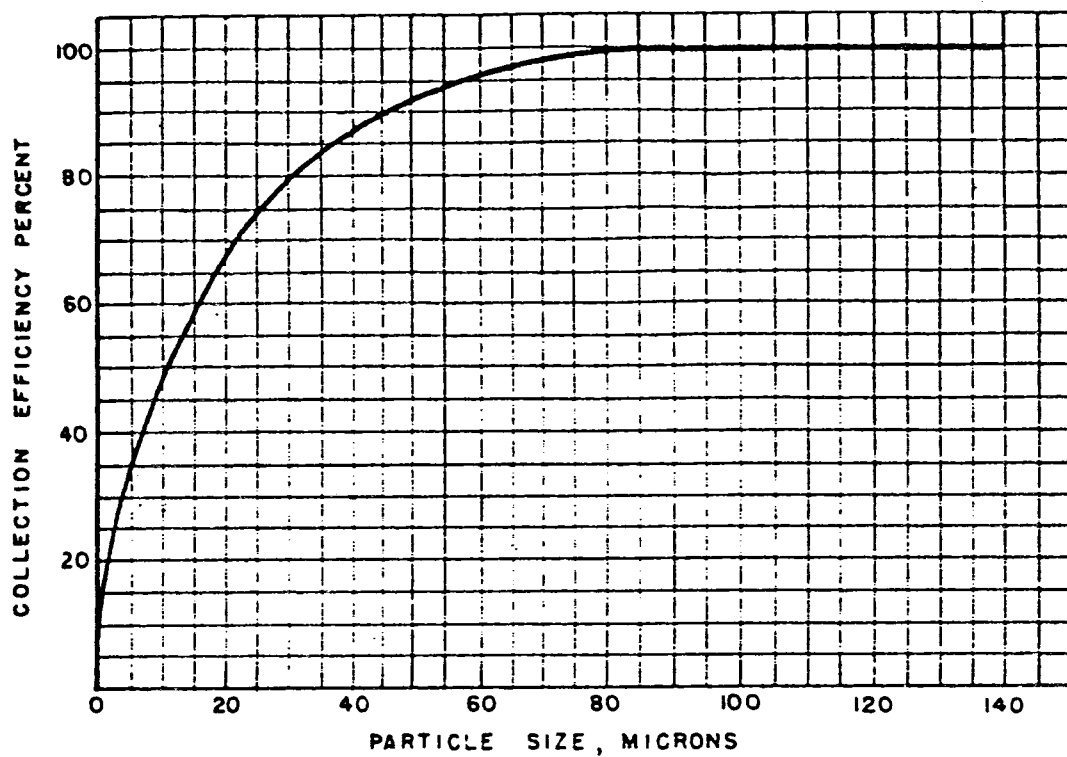


FIGURE 2-99. CYCLONE FRACTIONAL EFFICIENCY CURVE

complement each other to provide good efficiency over a wide range of gas flow and dust loading conditions.

**i. Application for Reinjection.** Fly ash carried over from a spreader stoker often contains a high percentage of unburned carbon. This constitutes a loss in heating value and, therefore, efficiency. Since the particles are fairly coarse, a medium-efficiency cyclone can collect them effectively with a minimum of added fan horsepower. An additional small fan can then be used to reinject the collected material into the furnace for more complete combustion. This type of cyclone arrangement is typically used ahead of a precipitator or baghouse, which serves as the final collection device.

**j. Effect of Firing Modes.** The method by which the fuel is fired can have a major effect on the suitability of a mechanical collector for the application. This is due to differences in particle size distribution in the flue gas from the different firing modes. Thus, if the same coal were to be fired in two identical boilers, one using a spreader stoker and the other using a chain grate stoker, the mechanical collector could collect the ash from the spreader stoker fired boiler more efficiently, because it generates coarser fly ash. Table 2-6 illustrates the optimum expected performance of mechanical collectors for particulate removal in various combustion process applications.

**TABLE 2-6**  
**REMOVAL EFFICIENCIES OF UNCONTROLLED PARTICULATE**  
**EMISSIONS FROM COMBUSTION PROCESSES**

Fuel/Firing Mode Cyclone	Percent Removed Medium Efficiency	
	Multicyclone	
Oil/Steam or mechanical atomizer	30-40	40-50
Coal/spreader stoker	75-85	90-95
Coal/chain grate or underfeed stoker	50-70	85-90
Coal/pulverized	50-70	85-90
Coal/cyclone	30-40	40-50

## 2-33. FABRIC FILTERS.

Fabric filters, commonly called "baghouses", are used to remove particulate from the flue gas stream. The filters are made of woven or felted high-temperature fabric, such as fiberglass or Teflon. They are normally manufactured in the form of a cylindrical bag, although other configurations are possible. These elements are contained in a metal housing which has gas inlet and outlet connections, a dust storage hopper, and a cleaning mechanism. In operation, dust-laden gas flows through the cloth filters, and the dust is removed from the gas stream as it passes through the filter cloth. The filters are cleaned periodically.

**a. Housing Design.** For practical reasons, most baghouses

used for boiler flue gas are designed to operate under negative pressure and are located between the last heat trap and the induced-draft fan. Pressurized-type baghouses are very rare. Negative pressure baghouses are constructed with a welded steel, gas-tight housing. It is usually divided into two or more compartments, each having a dust collection hopper beneath it. The hoppers and housing are insulated, and the fan is located on the clean side of the collector.

**b. Filter Arrangement.** Filters are usually cylindrical but may also be of the flat panel type. The cylindrical types have the advantage of maximizing total cloth area per square foot of floor area, since they can be made very long. They typically have a length-to-diameter ratio of about 30:1. They can be arranged to collect the dust on either the inside or the outside of the cylinder. Flat panel filters consist of large, flat areas of cloth stretched over adjustable frames. Flow direction is usually horizontal. Flat panel filters have the advantages of frames. Flow direction is usually horizontal. Flat panel filters have the advantages of allowing slightly more filter area per cubic foot of collector volume and of allowing the panels to be manually cleaned by brushing if excessive dust buildup occurs.

**c. Filter Cleaning Methods.** The dust may be removed from the filters by several methods. The most common methods applied are shaking, reverse gas flow, and reverse pulse.

**(1) Shaking.** A few baghouse designs use a rigid frame and a motor-driven oscillator mechanism to gently shake the dust loose from the bags. However, this is rarely used on modern design units because it increases bag wear and shortens bag life.

**(2) Reverse Gas Flow.** See figure 2-100. The reverse gas flow cleaning method uses a fan to gently backwash the bags with high-volume, low-pressure, clean flue gas taken from the baghouse outlet. This causes the dust which has accumulated on the bags to drop off into the hoppers. Baghouses of this design use low air-to-cloth ratios and thus require more bags and a larger housing to handle the same gas flow. In addition, a spare compartment must be provided, since the compartments must be taken off-line for cleaning.

**(3) Pulse Jet.** See figure 2-101. The pulse jet cleaning method utilizes a short blast of high-pressure air (90-100 psig) to blow backwards through the bag and dislodge the dust so that it can drop into the collection hopper. This design has several advantages over the reverse gas flow method and is gradually becoming the dominant design in the industry. Its primary advantages relate to its higher air-to-cloth ratio and subsequently small physical size. This leads to lower initial cost, fewer bags, and lower space requirements. Other advantages are the

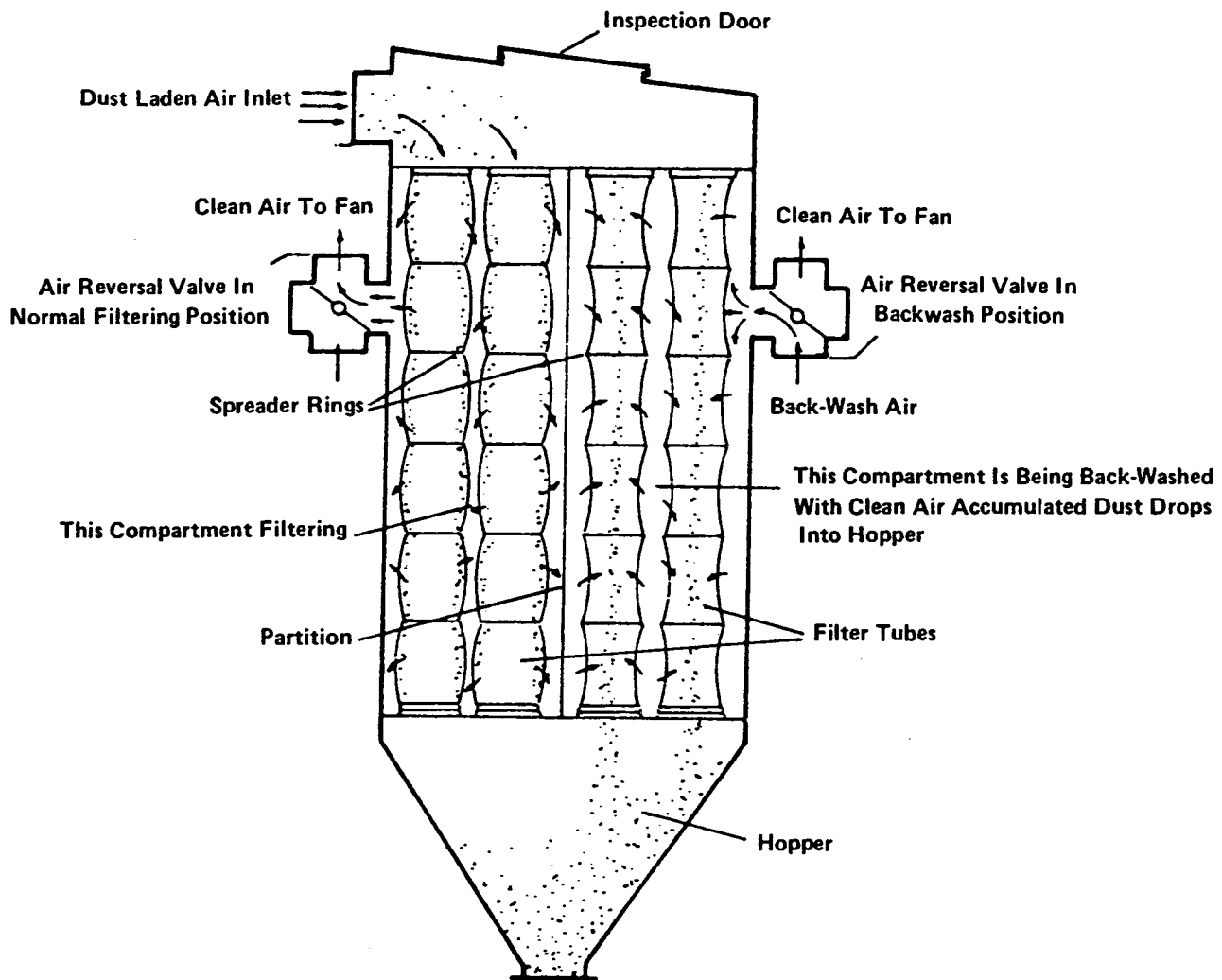


FIGURE 2-100. REVERSE FLOW BAGHOUSE

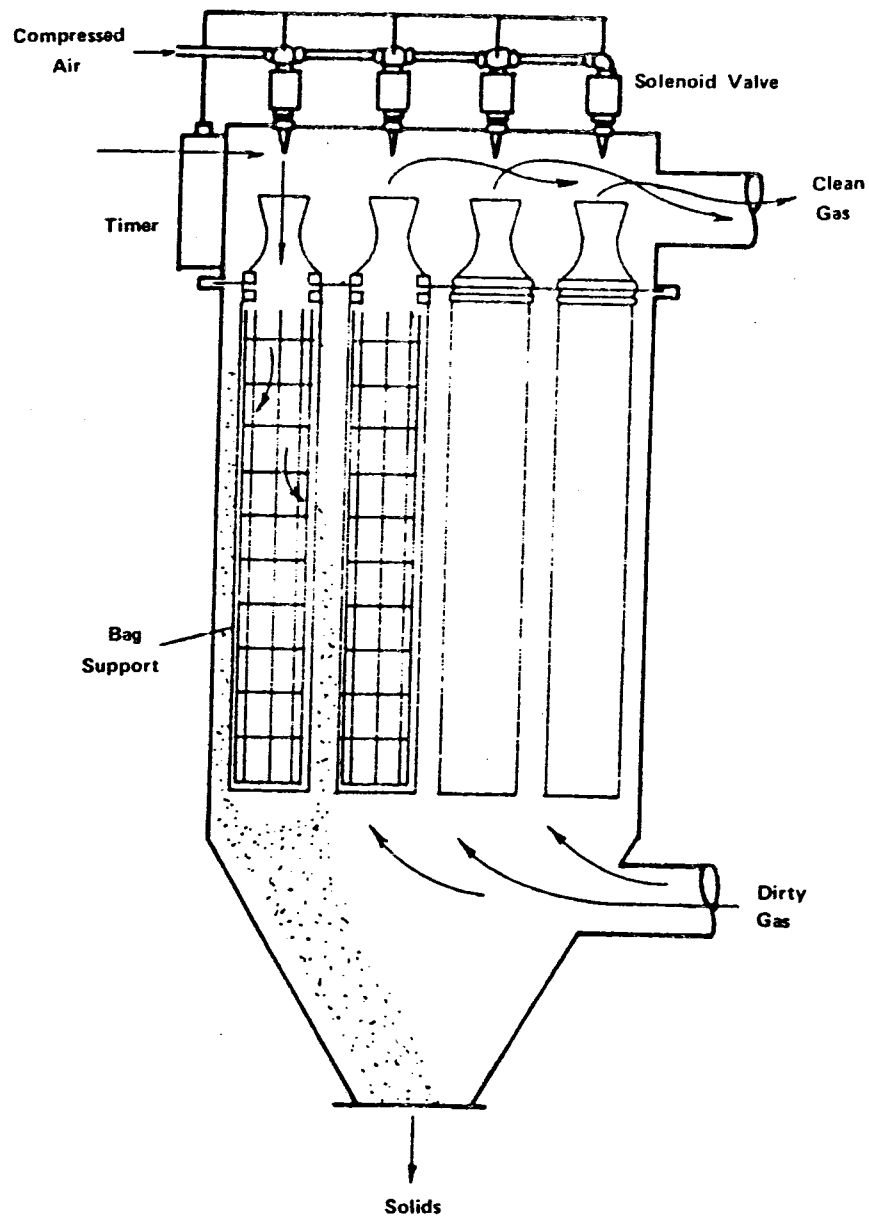


FIGURE 2-101. PULSE JET BAGHOUSE

lower horsepower requirements for generating the cleaning air, fewer moving parts, and the fact that compartments may be cleaned either on- or off-line. Its main disadvantage is that the bags, although fewer in number, must be considerably heavier, and therefore more expensive, in order to withstand the severe cleaning cycles.

**d. Energy Requirements.** The primary energy requirement of a baghouse is the fan horsepower necessary to move the flue gas through the unit. Resistance to flow arises from the pressure drop across the filter cloth, friction losses through ducts and dampers, and turbulent flow losses. Power is also required to drive the cleaning equipment.

**e. Application of Fabric Filters.** Properly designed fabric filters may be applied to most coal-fired Army boiler applications, either as part of a new installation or on a retrofit basis. The flue gas temperature into the fabric filter must be maintained above the sulfuric acid dew point but below the maximum permissible filter cloth temperature. Temperature requirements are discussed more fully under OPERATION (Chapter 3). Application to oil-fired boilers is not generally recommended, since unburned oil tends to cause the filters to plug or blind. A bypass around the baghouse is generally utilized for boilers which must burn both coal and oil.

## 2-34. ELECTROSTATIC PRECIPITATORS.

An electrostatic precipitator (ESP) is a device which removes particles from a gas stream by means of an electric field. The electric field imparts a positive or negative charge to the particle and attracts it to an oppositely charged plate. Provision is also made to remove the dust particles from the collection plates to dust hoppers located below the precipitator. The entire precipitator is enclosed in a metal housing which has a flue gas inlet and outlet and is connected into the boiler flues between the boiler and the stacks. ESPs may be operated under either pressure or suction conditions, with gas flow either horizontal or vertical. Many configurations are possible, depending upon the desired application. The most common applications for Army boilers are discussed below.

**a. Electrode Design.** Most electrostatic precipitators applied to Army boilers are of the parallel plate design with horizontal gas flow. The plates carry a positive charge and act as the collecting electrode. A large number of negatively charged high voltage discharge electrodes are spaced between the plates. These electrodes impart a negative charge to the particles in the gas stream which are then attracted to the positively charged collection plates. The particles adhere to the plates until they are removed by the cleaning system. This electrode system can be designed in two basic configurations.

(1) **Weighted Wire.** Reference figure 2-102. In the

weighted wire design, both the plates and the wires are suspended from the top and allowed to hang vertically by gravity. Weights are attached to the wire to maintain the proper tension. Precise alignment is necessary so that both sets of electrodes maintain the relationships required for best efficiency. Weighted wire construction has been used for many years, and is well proved and relatively inexpensive. It is a common type of installation for Army boilers, particularly older units.

(2) **Rigid Frame.** Some modern precipitators use rigid frame construction. In this type of construction, both the positive and negative electrodes are rigidly mounted at top and bottom to maintain precise alignment. This is somewhat more expensive, but is advantageous when extremely high collection efficiencies are required. It also reduces maintenance costs by minimizing or eliminating electrode wire breakage.

**b. Precipitator Location.** Precipitators may be located either in the hot regions of the flue gas stream, where temperatures are above 600° F; or after the last heat trap, where temperatures are between 300 and 350° F. These two locations are termed hot and cold, respectively.

(1) **Hot Precipitators.** Hot precipitators are generally applied to units designed for low sulfur coal because the characteristics of the ash from this type of coal make it difficult to collect in a cold precipitator. Particle resistance to collection decreases at the higher temperature. The ability to remove the particles from the plates and hoppers is also increased at these temperatures. Hot precipitators are more expensive, however, because they must be larger to handle the higher specific volume of the gas stream. Material selection, design for proper expansion, and structural considerations also become more critical at the higher temperatures. Finally, radiation losses from the precipitator housing increase at the higher temperatures, necessitating either more insulation or a reduction in boiler operating efficiency.

(2) **Cold Precipitators.** Cold precipitators are designed to operate at temperatures between 300° F to 350° F. They are smaller in construction and therefore cheaper than hot units for the same boiler size. However, they are not as effective in collecting ash from low sulfur coal. In addition, they may be subject to corrosion due to condensation of sulfuric acid at lower temperatures.

**c. Cleaning and Dust Removal.** Dust is removed from the electrodes by means of rappers. Rappers can consist of electromagnetic solenoids, motor-driven cams or motor-driven hammers which vibrate or impact upon the tops of the plates and wires. This causes the collected dust to slide down the electrode, eventually reaching the dust collection hopper at the bottom of the unit. Once collected in the hoppers, the dust is removed by the fly ash removal system.

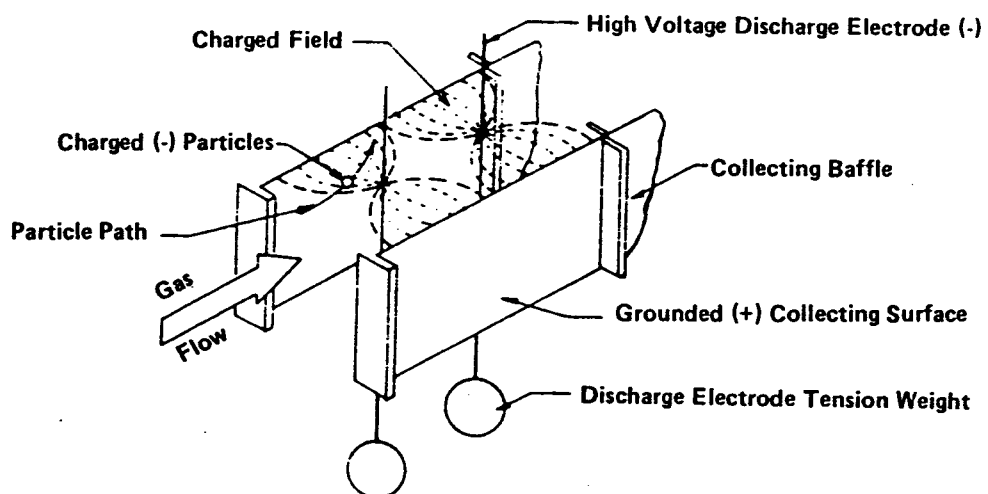


FIGURE 2-102. WEIGHTED WIRE TYPE  
ELECTROSTATIC PRECIPITATOR

**d. Energy Requirements.** The main uses of energy in an electrostatic precipitator are the fan horsepower to move the flue gas through the unit and the power required to maintain the electrostatic field. These two power usages are approximately equal. A typical electrostatic precipitator on a 30,000-lb/hr boiler would require about two to three brake horsepower in fan power consumption and two to three kilowatts to maintain the electrostatic field. The rappers and dust removal systems are other sources of power consumption.

**e. Application of Electrostatic Precipitators.** Electrostatic precipitators can be designed to function efficiently on almost any boiler, either for a new or retrofit installation, if sufficient physical space exists. However, it is important to have a good knowledge of the fuel analysis which will actually be burned, since this has a major effect upon the design of the precipitator. Once the precipitator has been designed and sized for a given fuel, major inefficiencies and operating problems can result from fuel changes.

## 2-35. WET SCRUBBERS.

A wet scrubber is a device designed to use a liquid to separate particulate contaminants from a flue gas stream. Although they are rarely used on Army boilers, they have some potential application and advantages over other types of particulate control devices and are thus discussed briefly in this manual. More details can be found in Army Manual TM 5-815. Most wet scrubber applications to Army boilers

would be of the wet approach venturi type (figure 2-103). It is very compact and has the capability to collect particles down to submicron size with about 99 percent efficiency, or even more if necessary. Its principle of operation is somewhat similar to a mechanical collector, but it adds the action of liquid scrubbing to the centrifugal and inertial forces. The incoming gas stream accelerates and atomizes the liquid droplets. These atomized droplets then wash the dust out of the gas stream in the same manner that a severe rainstorm can wash dust out of the atmosphere. Pressure drop through a wet scrubber increases with decreasing particle size and increasing collection efficiency. For a venturi scrubber applied to a coal-fired boiler, pressure drop typically ranges from 20 to 25 in-H<sub>2</sub>O. This creates a significant penalty in fan horsepower requirements and is one of the primary reasons that wet scrubbers are seldom applied to Army boilers. Other types of scrubbers can lower this horsepower requirement, but their collection efficiencies are also low. The other major disadvantage of the wet scrubber is its water usage. The cost of pretreating the water and the cost and complexity of treating the waste slurry from the scrubber discharge can be significant. The primary advantages of a wet scrubber are its compact size and its tolerance for extremely high gas temperatures. These two characteristics make it potentially useful for retrofit application where other types of control devices might not be applicable due to efficiency or space requirements.

# SECTION VI. AUXILIARY EQUIPMENT

## 2-36. FEEDWATER HEATERS.

Closed feedwater heaters of the tube and shell type are used to preheat feedwater going to deaerators and hot water boilers as well as for deaerating heating. These closed feedwater heaters can make use of turbine exhaust steam or waste heat generated in the boiler plant to improve overall plant efficiency. Deaerators, deaerating heaters, surge tanks, and condensate return tanks are discussed in chapter 4. Figure 2-104 illustrates a closed tube and shell heat exchanger used for feedwater heating.

## 2-37. PUMPS AND INJECTORS.

The selection and replacement of pumps require consideration of capacity and pressure requirements, the type and temperature of fluid to be handled, and the type of pump best suited for the job requirements. Performance characteristics vary widely, even among pumps of the same type and capacity. Pumps can be classified into four groups: centrifugal pumps, reciprocating piston pumps, rotary

positive displacement pumps, and jet pumps/injectors. The characteristics of these groups are discussed later.

**a. Installation.** The selection of a pump for a particular job involves many considerations, but once the pump is selected, successful performance depends upon details of the installation. This is particularly true where the pump must lift the fluid or when the fluid is heated. Greater care must be exercised in design and installation of the suction line than of the pump discharge. A strainer is required to prevent foreign objects from entering and clogging the pump or piping. The maximum suction lift or minimum suction lift or minimum suction head depends to a great extent upon the temperature of the water and the distance of the pump above sea level as noted in table 2-7. The following rules should be observed when installing a suction line to a pump. Disregarding any of the following rules may lead to unsatisfactory operation or complete failure:

(1) The line must be tight. A leak in the discharge line may be annoying, but a leak in the suction line may